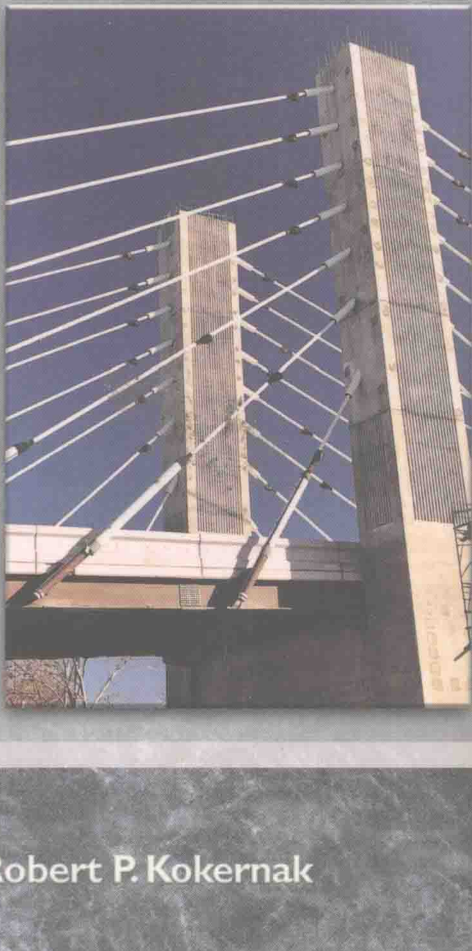
INTERNATIONAL EDITION

Statics *and* Strength *of* Materials

FIFTH EDITION



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Statics and Strength of Materials

Fifth Edition

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Dedicated to the memory
of
John F. Kokernak

About the Cover

(Left) The bearings shown are approximately 44 in. (1.1 m) in diameter, are made of medium carbon alloy steel, and are used on *rolling mills* which produce steel such as plate, strip, foil, and rod for use in a variety of manufactured products. Despite their large size, these bearings must satisfy very exacting standards: the maximum variation in wall thickness is typically less than 0.00012 in. (3 microns), and the outside of each bearing is polished so that surface irregularities do not exceed one millionth of an inch (0.025 microns). To achieve such precision, the material properties of steel must be carefully matched to the manufacturing processes used to produce these bearings. (*Courtesy of Morgan Construction Company, Worcester, Massachusetts, www.morganco.com.*)
(Right) On modern bridges of *cable-stayed* design, weights of both the roadway and its vehicular traffic are carried by steel cables which connect the bridge deck to massive supporting towers. Because the forces in these cables pull downward and sideways on the towers, the cable tensions must be adjusted so that side-to-side forces are in equilibrium. The 8-in. diameter cables shown here are protected by polyethylene tubes, and support a 650-ft bridge deck on four towers ranging in height from 110 to 140 feet.

Preface

The objective of this fifth edition is to cover statics and strength of materials at an elementary level, where calculus is not required. However, for instructors who use the text to teach in accredited programs in the technologies, sections requiring calculus are included. Those sections relate to centroids and moments of inertia of plane areas, and deflection of beams by integration. Marked with an asterisk, this material can be omitted without a loss of continuity.

Statics and Strength of Materials is written for students enrolled in the industrial technology or engineering technology curriculum, and in university-level courses for nonengineering majors, such as architecture. It is also useful for self-study and can serve as a reference for courses in materials, materials testing, machine design, and structural design.

This edition contains several new features, including a number of Application Sidebars scattered throughout the book. These pages describe real-life applications related to topics discussed in the text and serve to emphasize the fact that statics and strength of materials are not purely academic subjects. We have also included a new section on residential design utilizing tabulated values. Many students are aware of the fact that residential construction practices are influenced primarily by local or federal building codes. However, those same students are often unaware of any limitations within the code tables and cannot always make a connection between such tabulated values and the theoretical values obtained using traditional methods. We hope that the new material will help bridge this gap. Also, due to the increasing use of machine-graded lumber, a table of machine-stress rated (MSR) and machine-evaluated lumber (MEL) designations and properties has been added to the Appendix.

Aside from this additional material, the general plan of the book is unchanged. Care has been taken to present the various topics with clarity in a simple and direct fashion and to avoid information overload. To that end, more than 200 examples illustrate the principles involved.

Chapters 1 through 9 provide coverage of statics, while strength of materials is covered in Chapters 10 through 18. The chapters on statics begin with a review of basic mathematics. Trigonometric formulas and the component method are employed to solve concurrent force problems. A discussion of the resultant and equilibrium of nonconcurrent forces follows, with special emphasis on the theorem of moments. Then the force analysis of structures and machines, and concurrent and nonconcurrent force systems in space is presented. The chapters on statics conclude with friction, centers of gravity, centroids, and moment of inertia of areas. The chapters on strength of materials begin with the study of stress and strain in axially loaded members. This is followed by discussions of shear stresses and strains in torsion members, bending and deflection of beams, combined stress using Mohr's circle, columns, and structural connections.

The text includes more than 950 problems at various levels of difficulty for the student. Both the U.S. customary system of units and the international system of units (SI) are introduced and applied equally in the problems and examples.

The majority of the material in this book was originally written by H. W. Morrow, who prepared two preliminary editions for use at Nassau (NY) Community College from 1976 to 1979. These were followed by three editions, published in 1981, 1993 and 1998, by Prentice Hall. Subsequent editions represent a joint collaboration between Mr. Morrow and R. P. Kokernak of Fitchburg (MA) State College.

We would like to thank the following individuals for the help they provided with various aspects of the fifth edition: Neil Gow of Morgan Contraction Company; David Tourigny of Marceau's Industrial Belt Services; and Christine Woollett of The Royal Society. Special thanks to the people at the RANOR Corporation—John Duffy, Octave "Tibby" Thiboutot, and Shawn Ballou—whose contributions were numerous and invaluable. Finally, for their continued inspiration as this manuscript was being prepared, thanks to Amelia Kokernak, Abigail Smith, and Charlotte Kokernak, along with their grandmother, Jean, who helped get the whole project started many years ago.

We would also like to acknowledge the reviewers of this text: Dr. Eduardo De Santiago, Illinois Institute of Technology; Charles Drake, Ferris State University; and James Scudder, Rochester Institute of Technology.

Users of the text are encouraged to write the authors with suggestions for improvements in future editions. Such material may be sent via e-mail to *rkokernak@fsc.edu* or mailed directly to this address: Robert P. Kokernak, Department of Industrial Technology, Fitchburg State College, 160 Pearl Street, Fitchburg, MA 01420.

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Contents

*Sections denoted by an asterisk indicate material that can be omitted without loss of continuity.

Application Sidebars

1 Basic Concepts

◆ CHAPTER OBJECTIVES ◆

This chapter reviews the basic mathematical skills necessary to the study of statics and strength of materials. Before proceeding to Chapter 2, you should be able to accomplish each of the following tasks:

- Perform numerical computations and conversions using both U.S. customary units and the International (SI) System of Units.
- Use standard trigonometric formulas in the analysis of right and oblique (nonright) triangles.
- Solve groups of two and three simultaneous linear equations.

1.1 INTRODUCTION

Statics is that branch of mechanics involving the study of forces and the effect of forces on physical systems that are in equilibrium. Our reason for the study of statics is to determine all the forces that act on the system and the reactions to those forces.

Strength of materials, or mechanics of materials, establishes the connection between the external forces applied to a physical system, the resulting deflections or deformations of that system, and the intensity of the internal forces (stress) in the system. We study strength of materials to learn methods for the analysis and design of various load-bearing structures and machines.

Statics is considered in Chapters 1 through 9 and strength of materials in Chapters 10 through 18. Statics is one of the oldest branches of science. Its origins date back to the Egyptians and Babylonians, who used statics in the building of pyramids and temples. Among the earliest written records are the theories developed by Archimedes (287–212 B.C.), who explained the equilibrium of the lever and the law of buoyancy in hydrostatics. However, modern statics dates from about A.D. 1600 with the use by Simon Stevinus of the principle of the parallelogram of forces.

1.2 FUNDAMENTAL QUANTITIES: UNITS

The two fundamental quantities used in the solution of statics problems are force and length.

Force may be defined as the action of one body on another which tends to change the shape or state of motion, or both, of the other body. Aside from a simple push or pull which we can exert on a body with our hands, the force we are most familiar with is gravitational force. The gravitational force or attraction exerted by the earth on a body is the weight of the body. Other familiar forces are electrical or magnetic attraction, wind forces on a surface, automobile tire traction on the pavement, and so on.

Length is a measure of size or relative position. It is used to describe the size of a body and to locate the position of the forces that act on a body.

To describe a force we need to specify three things: magnitude, direction, and point of application. The magnitude of a force is given by a certain number of force units. The direction may be given by the angle the force makes with a selected reference axis. The point of application is the point at which the force is applied.

A length can be described by magnitude only and the magnitude is given by a certain number of length units. The magnitude of both force and length are defined by arbitrarily chosen units.

U.S. Customary Units

Engineers in the United States have commonly used the pound (lb) as the unit of force and the foot (ft) as the unit of length. The pound force is defined as the weight of a specific platinum cylinder placed at sea level and at a latitude of 45°. Other commonly used units of force are the kilopound (kip), equal to 1000 lb, and the ton, equal to 2000 lb. The foot is defined as 0.3048 meter. (See the following paragraph for the definition of meter.) Other units of length based on the foot are the mile (mi), equal to 5280 ft; the inch (in.), equal to 1/12 ft; and the yard (yd), equal to 3 ft.

International System of Units (SI)

A modernized version of the metric system, called the International System of Units, abbreviated SI, has been adopted throughout the world. The United States has been slow to convert to the SI system. Therefore, it will be necessary for engineers to be familiar with both the SI and U.S. customary systems of units.

In the SI system the meter or metre (m) is the unit of length and the newton (N) is the unit of force. The meter was at one time defined as the distance between parallel lines marked on a bar kept at standard temperature and pressure and located near Paris, France. The latest definition is based on the wavelength of a color line in the spectrum of the gas krypton. The advantage of such a definition is that it can be reproduced at any location. The meter is 3.2808 ft. The unit of force, the newton, is a derived unit. It is based on the change in the state of motion of a standard body on which the force acts. The newton (N) is approximately two-tenths of a pound of force or, more precisely, 1 N = 0.2248 lb. (The pound force is approximately 4-1/2 N or, more precisely, 1 lb = 4.4482 N.)

Weight and Mass

The *weight* or *force of gravity* on a body is determined from the *mass* of the body. The unit of mass is a kilogram (approximately equal to the mass of 0.001 m^3 of water) and is defined by the mass of a small platinum-iridium bar locked in an airtight vault near Paris, France.*

To find the weight W of a body in newtons (N) from the mass m in kilograms (kg), we use the equation

$$W = mg \tag{1.1}$$

where g is the acceleration due to gravity in meters per second squared (m/s^2). The acceleration varies only slightly from place to place on earth. We will use the approximation 9.81 m/s^2. For example, to find the weight of a body with a mass of 2.5 kg, we multiply by 9.81. $W = 2.5\,(9.81) = 24.5\text{ kg}\,(m/s^2) = 24.5\text{ N}$.

Multiples and submultiples of length and force commonly used are the kilometer (km), equal to 1000 m; the millimeter (mm), equal to 0.001 m; the kilonewton (kN), equal to 1000 N; and the meganewton (MN), equal to 1,000,000 N. Thus we see that the prefix milli means 0.001, or 10^{-3}, the prefix kilo means 1000, or 10^3, and the prefix mega means 1,000,000, or 10^6. See Table A.1 of the Appendix for other common prefixes.

1.3 SI STYLE AND USAGE

Precise rules of style and usage have been established in the SI system. Several of the rules follow.

A centered dot is used to separate units that are multiplied together. For example, for a newton · meter, the moment of force, we write N · m. This helps avoid confusion with the millinewton, which would be written mN.

Except for the prefix kilo (k) in kilograms, prefixes should be avoided in the denominator of compound units that are answers. For example, as a measure of stress we use N/m^2 rather than N/mm^2, to avoid having the prefix milli (m) appear in the denominator.

*The kilogram is the last scientific unit of measure defined by a physical contrivance, a single bar, rather than a constant of nature. Ongoing research is directed at defining the kilogram in terms of standards that can be duplicated anywhere. A possible definition may be based on Avogadro's number—a measure of the number of molecules present in the volume of a mole of gas (0.02241 m^3) at a fixed temperature and pressure. Researchers say that with luck the change may come within the decade.